TNO-report
TM-96-A039

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title

Computer Generated Environment for steering a simulated unmanned aerial vehicle

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date
1 October 1996

number of pages : 32 (incl. appendices, excl. distribution list)

TNO Human Factors Research Institute is part of TNO Defence research to which also belong:
TNO Physics and Electronics Laboratory
TNO Prins Maurits Laboratory

Netherlands Organization for Applied Scientific Research

titel	:	Computer Generated Environment for steering a simulated unmanned aerial vehicle (Computer gegenereerde omgeving voor het besturen van een gesimuleerd onbemand voertuig)
auteurs	:	Drs. J.B.F. van Erp en drs. B. Kappé
datum	:	1 oktober 1996
opdrachtnr.	:	A95/KM/372
IWP-nr.	:	788.1
rapportnr.	:	TM-96-A039

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In eerdere experimenten is aangetoond dat ondersteuning van de operator door het toevoegen van een Computer Gegenereerde Omgeving (CGO) aan het camerabeeld, de prestaties bij het besturen van de camera en het situationeel bewustzijn vergroot. Het huidige experiment is gericht op de mogelijkheden om tegelijkertijd het vaartuig en de camera te besturen, d.w.z. het volgen van een doelschip en het vliegen van een cirkel er omheen. Het experiment vergeleek de prestaties met vier typen display: twee zonder CGO (north up and heading up), en twee met CGO (in een 2D en een 3D uitvoering).

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REPORT DOCUMENTATION PAGE

1. DEFENCE REPORT NUMBER (MOD-NL) RP 96-0179	2. RECIPIENT'S ACCESSION NUMBER	3. PERFORMING ORGANIZATION REPORT NUMBER TM-96-A039
4. PROJECT/TASK/WORK UNIT NO. 788.1	5. CONTRACT NUMBER A95/KM/372	6. REPORT DATE 1 October 1996
7. NUMBER OF PAGES 32	8. NUMBER OF REFERENCES 27	9. TYPE OF REPORT AND DATES COVERED Final

10. TITLE AND SUBTITLE

Computer Generated Environment for steering a simulated unmanned aerial vehicle

11. AUTHOR(S)

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12. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

TNO Human Factors Research Institute
Kampweg 5
3769 DE SOESTERBERG

13. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Director of Navy Research and Development
P.O. Box 20702
2500 ES DEN HAAG

14. SUPPLEMENTARY NOTES

15. ABSTRACT (MAXIMUM 200 WORDS, 1044 BYTE)

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In previous experiments, it was shown that augmentation of the camera image by adding a Computer Generated Environment (CGE) improves performance in controlling the camera and enlarges situational awareness. The present experiment focuses on the possibilities of operating both the airframe and the on-board camera simultaneously, e.g. tracking a target ship while flying a circle around it. The experiment compared performance in four display type conditions: two without augmentation (respectively north up and heading up), and two with augmentation (respectively a 2D CGE and a 3D CGE).
The results show that the CGE is successful in supporting airframe control, without affecting tracking performance. No differences were found between the 2D and 3D CGE, and no differences were found between the north up and heading up displays without CGE. On the basis of these results, it is recommended to investigate the effects of integrating more information into the CGE (i.e. electronic maps), and to explore the possibilities of switching between 2D and 3D. Moreover, more basic knowledge should be acquired concerning the (visual) perception and discrimination of combined airframe, camera, and target motions.

16. DESCRIPTORS	IDENTIFIERS
Data Transmission Human Performance Remotely Piloted Vehicle Target Tracking Unmanned Aerial Vehicle	

17a. SECURITY CLASSIFICATION (OF REPORT)	17b. SECURITY CLASSIFICATION (OF PAGE)	17c. SECURITY CLASSIFICATION (OF ABSTRACT)
18. DISTRIBUTION/AVAILABILITY STATEMENT Unlimited availability		17d. SECURITY CLASSIFICATION (OF TITLES)

Managementuittreksel TNO Technische Menskunde, Soesterberg

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Institute:	TNO Human Factors Research Institute Group: Skilled Behaviour
Date:	October 1996
DO Assignment No.:	A95/KM/372
No. in Program of Work:	788.1

SUMMARY

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Rap.nr. TM-96-A039

TNO Technische Menskunde
Soesterberg

Computer gegenereerde omgeving voor het besturen van een gesimuleerd onbemand voertuig

J.B.F. van Erp en B. Kappé

SAMENVATTING

Twee belangrijke taken van een operator van een maritiem onbemand luchtvaartuig zijn het besturen van het vaartuig en de camera aan boord. De beschikbare visuele informatie is echter van lage kwaliteit, als gevolg van de lage capaciteit van de beeldverbinding tussen camera en operator. Dit leidt tot daling van de prestaties bij zoek- en volgtaken en tot verlaging van het situationeel bewustzijn.

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1 INTRODUCTION

1.1 Sketch of the problem

Maritime Unmanned Aerial Vehicles (MUAVs) are fixed- or rotary-winged airframes which are able to fly autonomously, and carry one or more sensors. MUAVs may be brought into action for different military missions, including battle damage assessment, reconnaissance, searching, identification, tracking of targets, and as relay station for communications. During flight, operators are responsible for one or more MUAVs. Their main tasks are [1] operating the payload (generally a TV camera), and [2] operating the airframe.

Compared to real flying, in operating an unmanned vehicle, the flow of information is very poor: i.e. no vestibular feedback on airframe attitude, no proprioceptive feedback in control devices, and degraded visual information. This last subject is the main focus of the present research project at TNO Human Factors Research Institute.

The main source of visual information for MUAV operators are the images of the outside world provided by the on-board camera. These images are of degraded quality for two reasons: first, the inherent characteristics of a camera–monitor system, e.g. restricted spatial resolution, lack of stereoscopic cues (see Van Erp, 1996), and second, because of the need to limit the data link between payload and operator. This is to reduce costs, and to prevent enemy jamming and detection. This restricted data link may, amongst others, result in lower spatial resolution, lower update rate, and a restricted field of view. For example, state of the art systems have a capacity of 500 kb/s (AGARD, 1995) available for images. Low update rate and low spatial resolution combined with a limited field of view (often only 5°), and little points of reference at sea lead to serious problems for the human operator, including loss of situational awareness (Chavand, Colle, Gallard, Mallem & Stomboni, 1988; Mestre, Savoyant, Péruch & Pailhous, 1990), and poor performance in target search and tracking tasks (see Eisen & Passenier, 1991; Swartz, Wallace, Libert, Tkacz & Solomon, 1992; Agin, Hershberger & Lukosevicius, 1980; Swistak, 1980).

Since 1994, the TNO Human Factors Research Institute undertakes exploratory studies for The Royal Netherlands Navy regarding support for MUAV-operators. This includes experiments on coupled control in which subjects directly operated the camera footprint (Van Breda & Passenier, 1993), and semi-automated systems, in which airframe translations were compensated by camera rotations (Korteling & Van der Borg, 1994). These experiments showed that operator support could be effective, but that the operator looses a part of the control over airframe and camera, which is sometimes undesirable (i.e. flying circles around targets and keeping distance is impossible without full independent control of the airframe), and may lead to loss of situational awareness.

1.2 Conventional versus augmented displays

In order to resolve this problem, a new principle of operator support was introduced: synthetic image augmentation. The principle is based on the idea that part of the visual

information may be generated at the control station, rather than via the camera–monitor system. Generating this information than is independent of the data link between airframe and operator, while the information is of high quality. i.e. high update rate, and sufficient structures. Actual position and heading of the airframe, actual heading and pitch of the camera, and input to airframe and camera, can be used to create a view on a Computer Generated Environment (CGE). The view on this environment (for example a grid which is (virtually) depicted at sea level) is coupled to the position and direction of the camera on-board the airframe. Above mentioned information is present at the control station, and is updated with high frequencies (updating of this information requires little data flow and is via a different channel than the images from the camera). This denotes that the view on this CGE may be depicted with arbitrary field of view, zoom factor, resolution etc. The visual motion information of the CGE provides information which is equivalent to the information an operator on-board the airframe would perceive. Therefore, we call this new principle **ECOLOGICAL COMPATIBLE**. Providing ecological compatible information by means of the CGE allows the use of low-level neuronal mechanisms normally used for processing information concerning the basic properties of the optic array (Gibson, 1950, 1966, 1979), such as layout, flow, and motion characteristics. Obviously, utilising such mechanisms will result in reduced operator workload compared with the traditional methods of operator support.

A view on a CGE is not identical to known principles of image augmentation. Image augmentation rests on the principle of adding information to the displays or images of the real world, and have to be transformed to the real world as such. A view on a CGE rests on a completely virtual world, which may be combined with images of the real world, but this does not necessarily have to be so.

In two previous experiments, this new principle of a view on a CGE was tested, in which the operator was only controlling the camera in respectively a tracking and a search task. In these experiments the CGE appeared very successful (Van Erp, Korteling & Kappé, 1995; Van Erp, Kappé & Korteling, 1996). Camera tracking errors were reduced by 50% (at 0.5 Hz update frequency); search times and search efficiency by 25%. Both experiments were focused on perception of camera and platform motions (spatial awareness), operating the airframe itself was not part of the task. However, previous research of Van Breda and Passenier (1993) showed that camera tracking with separate controls (one joystick for the airframe, one for the camera) is poor with a compelled standoff distance of 2000 m. Even with a high update rate of the camera image (10 Hz), the percentage of the time that the target was visible was only about 60%, and the standoff error was about 350 m. Van Breda and Passenier used a combination of two displays: a simulated camera image, and a north up simulated radar image with airframe, target, camera footprint, and a digital indicator of the footprint distance to the airframe.

The present experiment evaluates the use of the CGE to develop a display which enables double stick control. Two important parameters in the design of the display are frame of reference (camera, ego, or world referenced[1]), viewing direction (2D or 3D), and depiction of standoff distance (digital or pictorial). Before going into the displays currently tested, these topics will be discussed in the next sections.

1.3 Ego- versus world-referenced displays

Operators of Unmanned Aerial Vehicles must perform two fundamentally different types of task: steering the airframe along the desired route, and searching for and tracking of targets and other relevant points in 3D space. The two types can be characterized by two different states of knowledge, respectively local guidance and global awareness (Prevett & Wickens, 1994). The knowledge required for local guidance tasks predominantly needs correspondence between display and control in terms of left, right, in front etc. This means that local guidance requires an ego-referenced display: display and control must correspond to the actual attitude of the vehicle (heading-up). On the contrary, the knowledge needed for global awareness must be presented in a world referenced display (north-up) to support interchange with other information sources (Wickens, 1992; Tolman, 1948, see also Roscoe, 1968).

1.4 2D versus 3D egocentric displays

Egocentric displays may present the same information, but display it with different elevation angles (angle between viewing direction and the sea plane), e.g.: 90° in a 2D display, or 45° in a forward looking display. Prevett and Wickens (1994) claim that a 3D representation has advantages for local guidance, as long as it is ego-referenced. The characteristics of an ego-referenced 3D display are more ecological (Warren & Wertheim, 1990): correspondence between display and controls, forward cone of visual space, zoomed-in (closer is more important), and the 3D perspective. However, a 2D world referenced representation is beneficial for global awareness of the operator. Prevett's and Wickens' claims are confirmed by the results of experiments in a flight simulator, in which they compared a 2D display, with a fully ego-referenced 3D display (Haskell & Wickens, 1993; Prevett & Wickens, 1994). In the 3D display, the tracking error (lateral and vertical axis) is reduced, but scores on a situational awareness questionnaire were lower.

The character of an ego-referenced display is determined by the elevation angle. An elevation angle of exactly 0° (looking down) or 90° (looking to the horizon) leads to compression of one dimension, and thus to a 2D display. Values between 0° and 90° lead to 3D representations with different characters. Ellis, Kim, Tyler, McGreevy and Stark (1985)

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[1] During flight, the operator task is very diverse. The various aspects of the task have different demands on the orientation of the accompanying display(s). One can distinguish three orientations for the displays for the MUAV operator: [1] view up for the camera image, [2] heading up for operating the airframe, [3] north up for displays containing survey-information (i.e. radar displays, electronic maps).

systematically varied the elevation angle between 0° and 90° with 15° steps. They found a U-shaped tracking error curve, with best performance at 45°. Kim, Ellis, Tyler, Hannaford and Stark (1987) replicated these results, and found little effects in the range between 30° and 60°. In this studies, the tracking error of all axis were summed.

One might argue that varying the elevation angle has different effects on lateral and vertical tracking: larger elevation angles support lateral tracking, smaller support vertical tracking. In flight, vertical tracking is often more important than lateral tracking (Fadden, Braune & Wiedemann, 1991). In operating Unmanned Aerial Vehicles this is not. UAVs often fly at a fixed altitude, and operating the airframe becomes a 2 DOF task (controlling only longitudinal speed and rotational speed). Of course, one may expect that elevation angles larger than 45° will support lateral tracking, at the cost of vertical tracking performance.

1.5 Digital versus pictorial presentation of the standoff distance

The actual standoff distance to the target is important information for the operator of the airframe. For example, this information is needed to prevent the airframe from coming too close to the target, and for flying circles around the target. The actual standoff distance can be depicted in several ways, i.e. by digital indicators or pictorial indicators. Roscoe (1968) describes six principles for airborne displays, of which three are applicable to the present experiment, and will therefore be discussed.

First, there is the principle of display integration, which states that it is beneficial to integrate indicators into a single (coherent) presentation. Second, the principle of pictorial realism states that graphically encoded information (symbols) can be readily identified with what they represent, and digitally displays do not. Third applicable principle is that of pursuit tracking, which states that pursuit tracking (motions of target and self both depicted) is superior to compensatory tracking (motions of target and self combined in one indicator)

1.6 The present experiment

The present experiment is set up to explore the possibilities of a Computer Generated Environment (CGE) in operating the airframe. Although the different components of the optic flow transformation independently specify MUAV translations and MUAV or camera rotations (Koenderink, 1986; Kappé & Korteling, 1995), the environment generated in the camera image seems unsuitable for operating the MUAV. For instance, under some conditions, separating the camera motions from the airframe motions is impossible (e.g. with large pitch (equivalent to looking down), camera rotations produce the same flow as airframe translations). In the present experiment, the displays for operating the airframe and for operating the camera are separated. Next to the camera screen, a second display is presented, depicting the information needed for flying the airframe. The information presented on this display was varied within four display types conditions.

All displays included the same symbol for the position of the airframe (projected at sea level), including airframe heading; the same symbol for the camera footprint; and a digital distance indicator for the distance from airframe projection to target (2D distance, altitude of airframe was held constant). The distance indicator was only updated when the target was within 3° of the centre of the camera image, all other information presented was updated with 30 Hz.

Four displays were tested, two with, and two without a CGE (see Table I). The two displays without a CGE were respectively north up (as used by Van Breda and Passenier), and heading up (see Fig. 1). The two displays with the CGE were with elevation angles of respectively 90° (looking downward, 2D) and 48° (looking forward (3D). The CGE used can be divided in two parts: first a grid of parallel and perpendicular lines, positioned at sea level, and second two circles at 2000 and 2500 meters around the position of the target (see Fig. 1).

The four displays are chosen to examine the following display parameters besides the effect of the CGE: north-up versus heading up (see § 1.3), and 2D presentation versus 3D presentation (§ 1.4).

Table I Characteristics of the four displays used in the experiment.

Display	heading up?	CGE?	3D?
I	no	no	no
II	yes	no	no
III	yes	yes	no
IV	yes	yes	yes

Task difficulty and display type

The CGE provides high quality visual motion information, and direct feedback on operator input. Since the information presented by indicators is per definition an abstraction of reality, mental operations are required to transform this information into a sense of camera and airframe state. Such mental operations, even when minimized, always consume attentional resources and increase operator workload.

On the basis of the above, we expect that the CGE may lower task demands. Therefore, we introduced a second independent variable to vary task demands or task difficulty. Larger task demands will possibly lead to larger advantage of the CGE. Task difficulty was varied by varying the speed of the airframe: 60 knots/h, 120 knots/h, and 180 knots/h. We expect that the airframe speed does not influence performance in the displays with CGE, but does when no CGE is present.

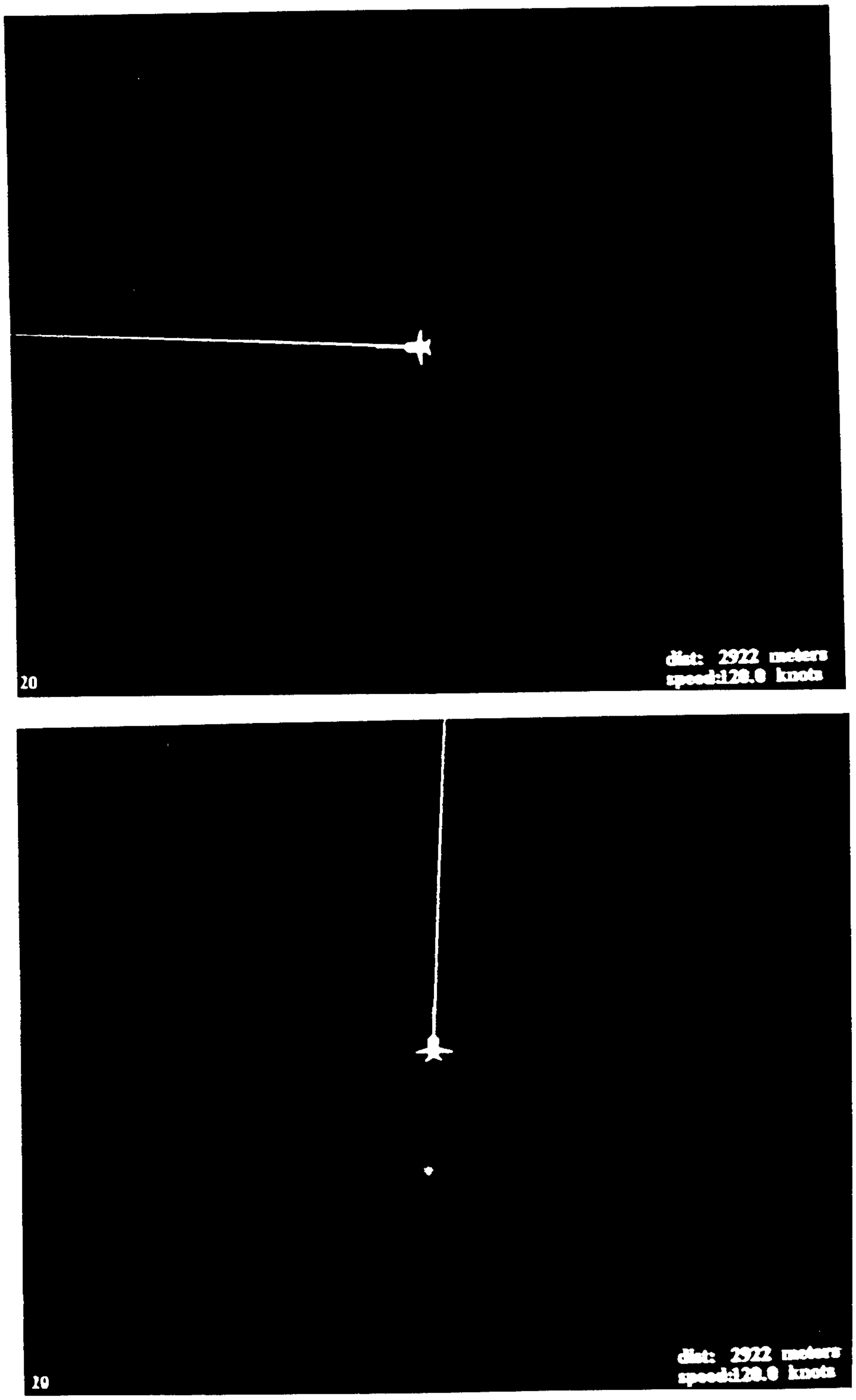
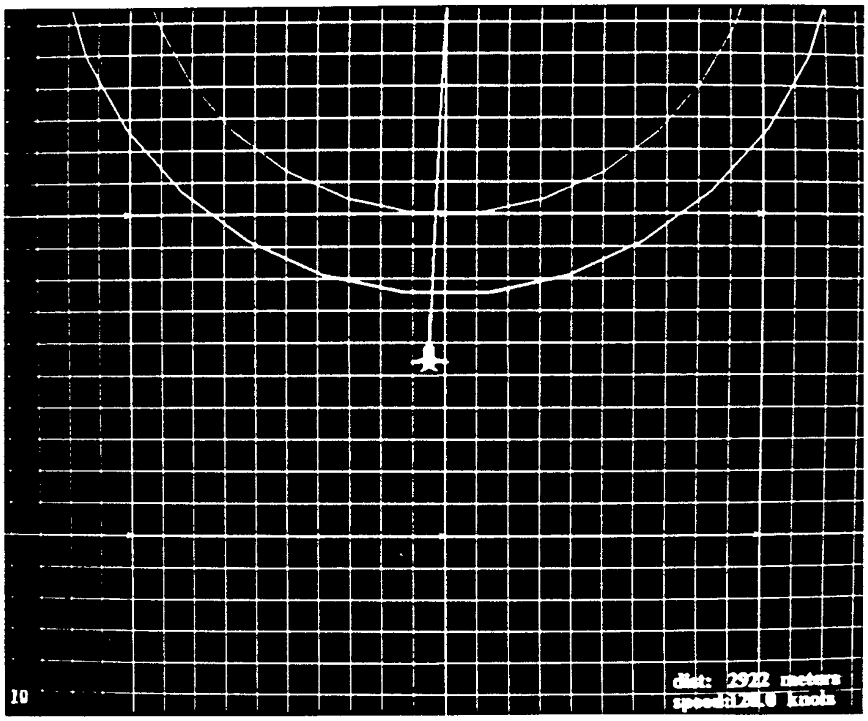
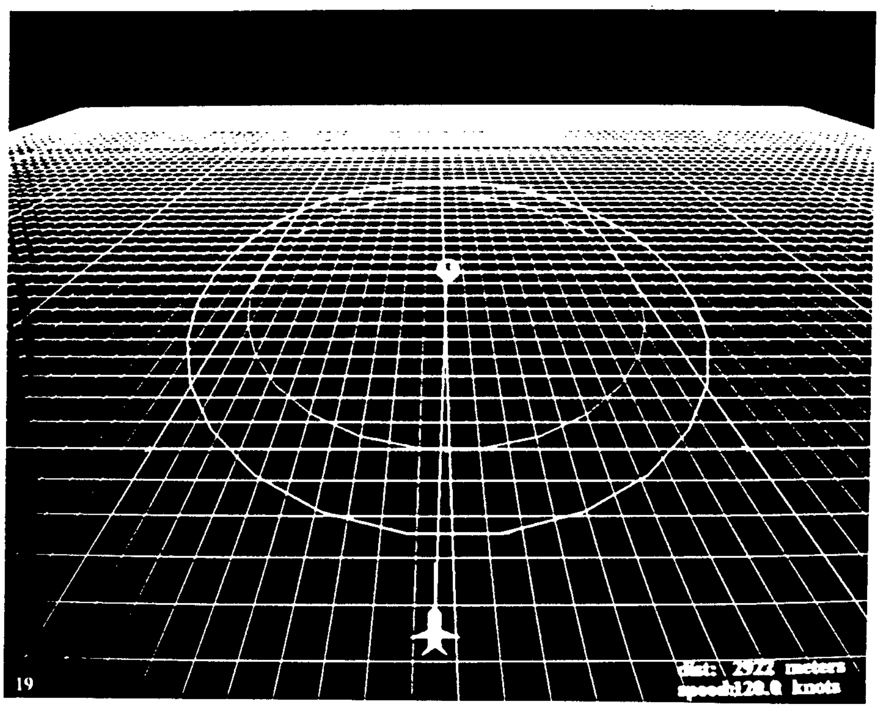


Fig. 1 The four types of display for operating the airframe: I north-up, II heading up, III heading up with downward looking CGE (2D), IV heading up with forward looking CGE (3D). Both III and IV on next page.

Fig. 1 (Cont'd)





2 METHODS

2.1 Subjects, task, and dependent variables

Subjects

Ten higher educated, male subjects (age 18−26 years, mean 22, s.d. 2.5 years) participated in the experiment. All subjects had normal or corrected-to-normal vision. The subjects were payed for their participation, and had no experience with similar operator tasks.

Task

Subjects had to operate both the airframe and its TV camera by means of two joysticks: rotations of the airframe (left joystick), and heading and pitch of the camera (right joystick). A target ship on a further empty sea had to be tracked as accurately as possible with the camera, i.e. keeping the stern of the ship in the centre of the camera image. Operating the airframe meant flying a circle around the target ship (always counter clockwise), while keeping a standoff distance of 2250 m, and avoiding coming closer than 2000 m (see Appendix IV for complete instructions in Dutch). At the beginning of each trial, the camera was pointed at the target ship, and the airframe flew in the direction of the target ship. The standoff distance at the beginning of each trial was such, that the airframe would reach the minimum standoff distance of 2000 m in exactly 20 seconds if the target ship would be at a stationary position.

The instructions contained two important aspects. First: never come closer than the minimum standoff distance of 2000 m, second: try to maintain a standoff distance of 2250 m.

Dependent variables

On the basis of the instructions, the following different dependent variables were used for controlling the camera, and the airframe:

- controlling the airframe:
  - **too close (%):** percentage of time that the airframe is closer to the target than the minimum standoff distance of 2000 m.
  - **se standoff distance (m):** standard error of the standoff distance from the prescribed distance of 2250 m. This dependent variable indicates if the subject is able to keep the dictated standoff distance of 2250 m.
  - **sd lateral speed (m/s):** standard deviation of the lateral speed, which is at a fixed speed a measure of course instability. Lateral speed is the derivate of the standoff distance in time.

- controlling the camera:
  - **tracking error (°):** root mean square of the camera tracking error, heading and pitch angles combined.

2.2 Image and display

Subjects had two screens (Mitsubishi colour display monitor HL7955SBK, 38×27 cm): one with the simulated camera image (800×600 pixels), and one so called tactical display (1280×1024 pixels), which depicted the information used to operate the airframe. The camera image was generated by a Evans & Sutherland ESIG 2000 image generator and depicted a sea with slight structure and the target ship. In the centre of the screen a circle of 3° diameter was drawn, which could be used as sight. The field of view was 5° diagonal when the target was in sight. If the subject was loosing the target, the field of view of the camera image was gradually increased to a maximum of 50° diagonal. Normally, the operator would have to control the zoom factor himself by some control button. Because we are not interested in this aspect of the operator task, this was automated.

The tactical display was generated by a Silicon Graphics Iris 4D image generator. In all conditions it contained a symbol for the projection of the airframe at sea level (set at a size of 80×80 m), the actual heading of the airframe (line segment set at 100 m), a symbol for the footprint of the camera (pixel map set at 32×32 pixels despite camera pitch), and a digital indicator for the standoff distance. In all conditions horizontal field of view of the tactical display was 120°, vertical field of view was 96°. In display condition IV (forward looking CGE), camera pitch was 48°. In the conditions with a CGE, the tactical display depicted a grid at sea level, and distance circles around the target position. The grid consisted of a pattern of parallel and perpendicular lines, and was north-orientated (north indicated with arrows at the intersection of grid lines). The distance between two parallel grid lines was 200 m. The distance circles were drawn at 2000 m (yellow) and 2500 m (red) distance from the last updated target position.

The digital distance indicator, and the distance circles (as for depicting the motions of the target ship) were refreshed if the target was within 3° of the centre of the camera. Only when the camera is pointed at the target, the standoff location and standoff distance could be calculated on the basis of actual position, heading and pitch of the camera. Normally, the operator would have to push a button when the target ship is in the middle of the camera image, to update the position of the target ship. As with controlling the zoom factor, we were not interested in this aspect of the operators task, therefore, it was automated as well. Update rate of the tactical display was 30 Hz. This means that all operator input to the airframe or the camera was immediately depicted in the tactical display. This is possible on the basis of the following parameters of the system: airframe position, airframe heading, airframe speed, camera heading, and camera pitch. These are all updated with high frequencies, and relatively independent from the datalink capacity for camera images.

2.3 Mock-up and instrumentation

The experiment was conducted in the TNO-TM RPV Research Simulator. This facility is specially designed for simulating RPV missions (Korteling & Van Breda, 1994). The subject was seated in a chair on the left side of the operator table. The chair could be adjusted to personal comfort. The two spring loaded joysticks (square type, RS type 162-732) were

placed on the operator table at a comfortable distance for the right and left hand. The right joystick controlled the heading and pitch of the camera (left/right deflections: left/right rotations, fore- and backward deflections: pitch), the right joystick controlled the heading of the airframe (left/right deflections: left/right rotations). Rotation of both the airframe and the camera, and pitch speed were linear dependent on joystick deflection. In all directions, a 2% deflection resulted in no speed changes, full deflection resulted in the maximum rotation speed.

The two monitors were placed at eye height at a distance of approximately 60 cm. The camera screen was placed right, the tactical display in front of the subject.

The instructor sat in a control room with direct intercom contact with the subject, and had the same images at his disposal. Further instrumentation consisted of computers for scenario and data storage (5 Hz sampling frequency), and for supervisory functions.

2.4 Parameters of MUAV system, and target ship

MUAV

The airframe always flew at an altitude of 2000 m. The speed of the airframe was fixed at 60, 120, or 180 knots/h. The camera was not heading stabilized, which means that a rotation of the airframe results in the same rotation of the camera. Pitch/rotation rate of the airframe and camera was based on the following formula and parameters (first order control):

$$\text{rate} = A \times (\text{actual rate}) + (B \times \text{input signal}), \text{ with}$$
$$A = 1-(\Delta t/c_t)$$
$$B = \text{gain} \times (\Delta t/c_t)$$

for camera rotation:	$c_t = 0.5$ s, gain $= 0.35$
for camera pitch:	$c_t = 0.5$ s, gain $= 0.70$
for airframe rotation:	$c_t = 3$ s, gain $= 0.53$

Target ship

The target ship was a trawler (size 70 m). Each scenario of 200 s consisted of changes in longitudinal and/or rotational speed every 30 s. Speed varied between 20 knots/h and 40 knots/h.

Scenarios

Each scenario lasted exactly 200 s. The initial position was with the camera pointed at the target ship, the heading of the airframe was towards the target, and the initial standoff distance was such that the airframe would reach the minimum standoff distance in 20 s if the target was at a steady position. During the 200 s scenario, the target changed its course and/or speed every 30 seconds.

2.5 Independent variables, statistical design, and procedures

Independent variables

Two independent variables were used: speed of the airframe (three levels: 60, 120, or 180 knots/h, and display type (four levels: north-up, heading-up, 2D CGE, and 3D CGE).

Statistical design

A full factorial within subjects 4×3 block design was used. This means that every subject finished four display blocks, each consisting of scenarios with airframe speed 60, 120, and 180 knots/h. Within each of the twelve cells per subjects, five scenarios were run, leading to 15 different scenarios for each display type. Those 15 different scenarios were run under each level of display type, but randomised over the three levels of speed. Order of the independent variable speed was balanced across display type, independent variable display type was order balanced across subjects.

Before analysis, the data was cleaned: for each dependent variable, observations more than 3 SD from the general mean were marked as missing data. Due to a failure in data storage procedure, the total of six observations were lost, these were marked as missing cells as well. All missing data was replaced with the general mean for that dependent variable.

First analysis was a 3 way MANOVA with the dependent variables on controlling the airframe. Subsequently, each dependent variable was analyzed by a 10 (subject) × 4 (display type) × 3 (speed) ANOVA with the statistical package STATISTICA 5.0®. Each cell consisted of five observations. Significant main effects and interactions were more closely analyzed with a post-hoc Tukey test.

Procedures

Subjects always came in pairs and for two consecutive days. After completion of five scenarios in one condition, the subject could rest, while the other completed a condition. Day 1 was spent with the general introduction and training, and the first half of the experiment, day 2 was spend with the second half of the experiment.

After arrival on the first day, subjects received a brief written explanation of the general nature and procedures of the experiment, and the basic instructions. The instructor verbally explained the controls, images, procedures, purpose and task in more detail.

The training was divided in a session before the experiment (introduction training) and sessions during the experiment (recurrence training). The introduction training was always with the display type the subject would start with in the real experiment. This training consisted of three parts. In the first part, subjects only had to track the target ship with the camera, while the airframe automatically flew a circle around the target. In the second part, the subject only had to control the airframe, the camera automatically tracked the target ship. During this part, the subject received instructions on the optimal use of the display,

including handy tricks (i.e. use the angle between camera heading and airframe heading to control the standoff distance: between $-90°$ and $0°$ and $0°$ and $90°$ indicates approaching, etc.). In the third part, the subject both had to track the target ship and move the airframe in a circle around the target.

Each of the three parts consisted of three 200-s scenarios with three different speeds of the airframe.

After this introduction training session, the experiment would begin with the same display as the training was completed. Subjects finished the five scenarios in one condition (about 17 minutes) by turns. They were not allowed to watch each other during the experiment. When a display block (consisting of three airframe speeds, and a total of 15 scenarios) was finished, subjects received a brief recurrence training on the oncoming display type, consisting of [1] only operating the airframe with three different airframe speeds, and [2] tracking the target ship, and the airframe, again with three different airframe speeds (the tracking task did not change during the experiment and was therefore not trained separately for every display type). During recurrence training the instructor always sat next to the subject and explained the experimental condition, and the display.

3 RESULTS

This chapter presents the concise results of the statistical analysis. Means and detailed results are presented in Appendices I and II.

3.1 MANOVA on dependent variables of controlling the airframe

First a three way MANOVA was run on the independent variables on controlling the airframe: percentage time closer than the minimum standoff distance, the standard error relative to the standoff distance of 2250 m, and standard deviation of the lateral speed.

Table II MANOVA on the three dependent variables of controlling the airframe.

Effect	Wilks' Lambda	Rao's R	DFeffect	DFerror	p-level
subject	.699	1.778	27	368	.011
display	.455	2.591	9	60	.014
speed	.024	28.837	6	32	.000
subj × disp	.358	1.913	81	377	.000
subj × speed	.826	.461	54	376	1.00
disp × speed	.477	2.449	18	147	.002
subj × disp × speed	.442	.732	162	378	.989

Table II presents the results of the MANOVA, and shows three interesting effects: the main effects of display type and speed, and the interaction between display type and speed. These results are the cause of analysing each of the three independent variables separately with a three way ANOVA. The results of these ANOVAs are presented in Tables III−V in § 3.2.

3.2 ANOVAs on dependent variables of controlling the airframe

This section presents ANOVAs per dependent variable. Table III presents the results on the percentage of time the airframe was too close to the target than the prescribed minimum standoff distance of 2000 m.

Table III ANOVA on percentage of time closer to the target than the minimum standoff distance.

Effect	DFeffect	MSeffect	DFerror	MSerror	F-value	p-level
subject	9	67.65	480	13.28	5.09	.000
display	3	401.36	27	33.55	11.96	.000
speed	2	13.96	18	24.68	.57	.578
subj × disp	27	33.55	480	13.28	2.53	.000
subj × speed	18	24.68	480	13.28	1.86	.017
disp × speed	6	4.35	54	17.56	.25	.958
subj × disp × speed	54	17.56	480	13.28	1.32	.069

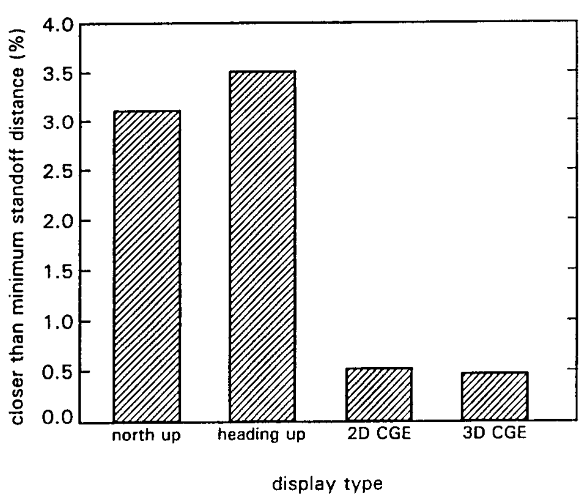


Fig. 2 Effect of display type on the percentage of time the airframe is closer than the minimum standoff distance.

The Table shows a germane effect of display type only (see Fig. 2). A post-hoc Tukey test shows that the display types without CGE (I and II) score worse than the display types with

CGE (III and IV). There are no significant differences between the displays within one group. This means that presenting CGE is a strong support for the operator to avoid crossing the minimum standoff distance.

Table IV presents the results of the ANOVA on the standard error of the standoff distance. This measure indicates the accuracy with which subjects can maintain the dictated standoff distance of 2250 m.

Table IV ANOVA on the standard error of the standoff distance.

Effect	DFeffect	MSeffect	DFerror	MSerror	F-value	p-level
subject	9	211828	480	7549	28.06	.000
display	3	263010	27	68715	3.83	.021
speed	2	426457	18	11363	37.53	.000
subj × disp	27	68715	480	7549	9.10	.000
subj × speed	18	11363	480	7549	1.51	.083
disp × speed	6	51639	54	16860	3.06	.012
subj × disp × speed	54	16860	480	7549	2.23	.000

The Table shows significant main effects of display type and airframe speed. A post-hoc Tukey test on display type reveals that only condition II (head up, without CGE) differs from condition IV (forward looking CGE). The post-hoc Tukey test on speed reveals a difference between 60 knots/h and both 120 and 180 knots/h. More interesting however, is the interaction between display type and speed (see Fig. 3).

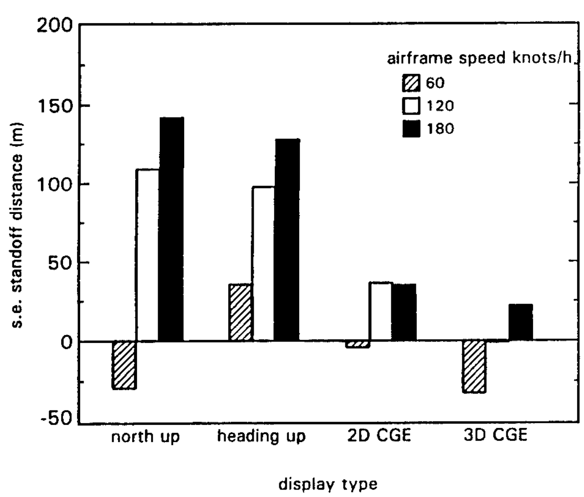


Fig. 3 Interaction of display type and airframe speed on the standard error of the standoff distance.

A post-hoc Tukey test reveals that the conditions may be classified into two groups (no differences within one group, significant difference between any combination of elements between groups). In the conditions with 120 and 180 knots/h and display type I (north up) and II (heading up, no CGE) the s.e. of the standoff distance is significantly higher than in all other conditions. This confirms our hypothesis that the positive effect of CGE is increased with higher airframe speeds.

Table V ANOVA on the s.d. of lateral speed.

Effect	DFeffect	MSeffect	DFerror	MSerror	F-value	p-level
subject	9	516.7	480	25.1	20.6	.000
display	3	1263.6	27	136.7	9.2	.000
speed	2	7523.0	18	118.9	63.3	.000
subj × disp	27	136.7	480	25.1	5.4	.000
subj × speed	18	118.9	480	25.1	1.7	.000
disp × speed	6	114.4	54	88.4	1.3	.276
subj × disp × speed	54	88.4	480	25.1	3.5	.000

The result of the analysis on the s.d. of lateral speed (see Table V) shows two relevant main effects: display type (see Fig. 4) and airframe speed. A post-hoc Tukey test reveals significant difference between the two displays without CGE (display I and II), and the two displays including the CGE (display III and IV). The s.d. of lateral speed decreases about 30% with the displays with the CGE.

A post-hoc Tukey test on the effect of airframe speed shows significant differences between all three levels; s.d. of lateral speed degrades with higher speeds of the airframe.

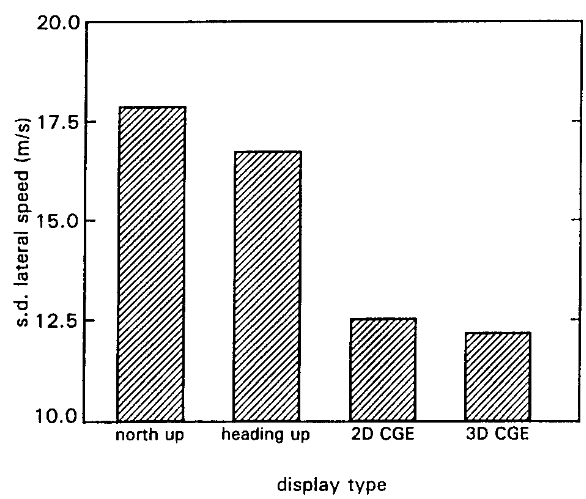


Fig. 4 Effect of display type on the s.d. of lateral speed.

3.3 ANOVA on camera error

The performance measure for controlling the camera was the root mean square of the tracking error. Table VI presents the results of the three way ANOVA.

Table VI ANOVA on the tracking error.

Effect	DFeffect	MSeffect	DFerror	MSerror	F-value	p-level
subject	9	5.23	480	.43	12.1	.000
display	3	1.85	27	1.55	1.19	.333
speed	2	3.73	18	.88	4.24	.031
subj × disp	27	1.55	480	.43	3.59	.000
subj × speed	18	.88	480	.43	2.03	.008
disp × speed	6	1.48	54	.57	2.61	.027
subj × disp × speed	54	.57	480	.43	1.31	.078

Table VI shows a main effect of airframe speed. A post-hoc Tukey test reveals only a significant difference between 60 knots/h and 180 knots/h. Tracking performance decreased with increasing airframe speed. The main effect of display type is not significant, but the interaction of display type with airframe speed is. However, a post-hoc Tukey test reveals no significant difference between any of the conditions. This indicates that there is no effect of display type on camera control.

4 CONCLUSIONS AND DISCUSSION

The present report concerns the use of Computer Generated Environments (CGEs) as support for operators of Maritime Unmanned Aerial Vehicles (MUAVs). Two major tasks in using and controlling MUAVs are steering the airframe and operating the on-board camera. For optimal flexibility and cost effectiveness, it is desirable to allocate both tasks to one operator. This means that this operator utilizes two joysticks: one for airframe heading and speed, and one for camera heading and pitch. Van Breda and Passenier (1993) showed that this so called "double stick" control, in combination with a traditional display, leads to poor operator performance.

In previous experiments (Van Erp, Korteling & Kappé, 1995; Van Erp, Kappé & Korteling, 1996) it was concluded that CGE-s are very successful in supporting camera control. However, in these experiments the operators task was limited to controlling the camera (no double stick control). Therefore, in the present experiment, a "double stick task" was introduced: flying circles around a target ship with an enforced standoff distance, while simultaneously tracking the ship with the on-board camera. Steering the airframe was supported with four display types, of which two included a CGE. Besides display type,

airframe speed was varied in order to vary task difficulty. Several dependent variables were used to measure airframe control and camera control.

4.1 Airframe control

Effect of display type

Main issue of the present experiment is whether a CGE can support the operator in controlling the airframe. To answer this question, subjects had to steer the airframe along a circle (radius 2250 m) around a moving target ship, without crossing the minimum standoff distance (2000 m). Information on camera heading and pitch, and airframe position, heading and standoff distance (updated when the target ship was in the middle of the camera image) was presented by four different display types. First display was north up without CGE, second was heading up without CGE, third was a heading up display with a 2D CGE, and forth a heading up display with a forward looking (elevation angle 48°) 3D CGE.

Besides the effect of the presence of a CGE, the four display types were chosen such that two additional display parameters could be examined: ego-centred versus world-centred frame of reference, and 2D CGE versus 3D CGE. The effects of the three parameters will be discussed below.

We expected that airframe control (no survey knowledge needed) would benefit from a heading up display (ego-centred), predominantly because this resolves problems concerning the reversal of control actions when flying south. However, the results do not show any difference between the first and second display type. The explanation may be that subjects only concentrate on the angle between airframe heading and camera heading, which should be 90° when the standoff distance is correct, smaller when the standoff distance is too large, and vice versa. Both displays depict the angle between both headings nearly alike.

The beneficial effect of the CGE is obviously present with respect to crossing the minimum standoff distance, and on the course stability. The presence of the CGE leads to performance increase of 30% or more. This indicates that the CGE helps subjects in perceiving the motions or course of the airframe (low level task), and helps them to prevent the airframe from entering the danger zone (higher level task). Another important advantage of the CGE is the depiction of standoff distance. First, this presentation is compatible with three principles of airborne display design as described in the Introduction (see § 1.5): principle of integration, pictorial realism, and pursuit tracking. Second, this presentation does not require the visual scanning or divided visual attention which the digital indicator requires. Depicting the digital indicator on or near the airframe symbol will lead to undesirable clutter.

The difference between the two display types including the CGE would indicate the value of a forward looking (3D) presentation. The information presented by a 3D display is more equivalent to the visual information an operator experiences who is really situated inside the vehicle. However, the results in this direction are not significant. This means that additional benefits of a 2D display are not on the expense of worse airframe control. The additional

benefits are for example the fact that a greater part of the CGE is visible, and the possibility to depict the grid in all directions around the airframe, and not only in the heading direction. This leads to possibilities of integrating other available information in the display, i.e. radar images, threat areas, cost lines or even complete electronic maps.

Because the functional difference between north up and heading up was not confirmed in this experiment, and concluding from the above mentioned results, the combination of a 2D CGE presented in a north up fashion seems to be an interesting alternative. This implies the possibility of enlarging the survey knowledge of the operator in a north up tactical display, which provides sufficient visual support to operate the airframe. In the Introduction, it was argued that on basis of the different aspects of the task of a MUAV operator, the possible advantages of three displays with three different orientations (view up to control the camera, heading up to control the airframe, and north up for the global/geographical situational awareness) may overcome the disadvantages, inherent to three different orientations. On the basis of the results of the present experiment, it is recommended that research on the combination of these orientations is conducted.

Effect of airframe speed

The dependent variable airframe speed was introduced because we expected an interaction of task difficulty (as increased by airframe speed) with display type. This interaction was indeed present for the standoff error. As expected, performance with tactical displays including the CGE was independent of the airframe speed, in contrast to displays without the CGE. This indicates that providing a CGE makes the operator less sensitive for task difficulty, and thus more capable of handling more difficult situations, i.e. multiple MUAV control, additional targets or threat areas, and low update rate.

4.2 Camera control

Effect of display type

The results show no effect of display type on camera control. This is relevant, because information on the position of the target ship is extracted from the camera image. This means that the quality of the CGE depends on tracking performance. Camera control was in the same order of magnitude as a comparable previous experiment (Van Erp, Korteling & Kappé, 1995), in which subjects only had to track a target ship with a camera, and thus were not required to devote attention to airframe control (same simulated camera image, same target ship, same controls). Thus double stick control does not necessary hamper camera control.

Effect of airframe speed

Camera control is however dependent on airframe speed: worse performance with higher speed. This is not of specific interest in this study, but one may expect that in real-time

missions in which camera control is important, lowering airframe speed may be an option to improve camera control.

4.3 Recommendations on future research

So far, the Computer Generated Environment was tested with low level operator tasks: controlling both the camera and the airframe. However, one might expect that CGE-s can support the MUAV operator on higher level tasks as well, i.e. mission planning and multiple MUAV control. Present (M)UAV systems utilize two or more operators. It would be beneficial if missions could be completed by a single operator.

Moreover, as mentioned above, there are possibilities to integrate different displays, such as electronic maps with the tactical display, and maybe even the camera image with the tactical display. A first step in exploring this is to study human factors in perceiving and discriminating combined airframe, camera, and target motions.

Third area of interest is improving the CGE, for example by introducing a variable elevation angle. One may expect that different tasks benefit from different elevation angles, and varying the elevation angle is on line possible.

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[2] On January 1, 1994 the name "TNO Institute for Perception" has been changed to "TNO Human Factors Research Institute".

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APPENDIX I Detailed statistical results: analysis of variance

Display type I = north up, no Computer Generated Environment (CGE).
Display type II = airframe heading up, no CGE.
Display type III = airframe heading up with downward looking (2D) CGE.
Display type IV = airframe heading up with forward looking (3D) CGE.

Percentage closer than the critical standoff distance (%)

Effect	DFeffect	MSeffect	DFerror	MSerror	F-value	p-level	means	
display	3	401.36	27	33.55	11.96	.000	I	3.11
							II	3.51
							III	0.52
							IV	0.47

Standard error of the standoff distance (m)

Effect	DFeffect	MSeffect	DFerror	MSerror	F-value	p-level	means	
display	3	263010	27	68715	3.83	.021	I	74.18
							II	84.53
							III	22.54
							IV	-3.40
speed	2	426457	18	11363	37.53	.000	60 knots/h	-7.17
							120 knots/h	58.75
							180 knots/h	81.81
disp × speed	6	51639	54	16860	3.06	.012	I / 60 knots/h	-28.80
							I / 120 knots/h	109.27
							I / 180 knots/h	142.08
							II / 60 knots/h	35.66
							II / 120 knots/h	90.06
							II / 180 knots/h	127.87
							III / 60 knots/h	-3.87
							III / 120 knots/h	36.46
							III / 180 knots/h	35.02
							IV / 60 knots/h	-31.66
							IV / 120 knots/h	-0.78
							IV / 180 knots/h	22.25

Standard deviation of the lateral speed (m/s)

Effect	DFeffect	MSeffect	DFerror	MSerror	F-value	p-level	means	
display	3	1263.6	27	136.7	9.2	.000	I	17.87
							II	16.74
							III	12.53
							IV	12.17
speed	2	7523.0	18	118.9	63.3	.000	60 knots/h	8.66
							120 knots/h	17.89
							180 knots/h	20.93

RMS camera error (°)

Effect	DFeffect	MSeffect	DFerror	MSerror	F-value	p-level	means	
speed	2	3.73	18	.88	4.24	.031	60 knots/h	.83
							120 knots/h	.91
							180 knots/h	1.10
disp × speed	6	1.48	54	.57	2.61	.027	I / 60	1.02
							I / 120	1.23
							I / 180	1.03
							II / 60	0.78
							II / 120	0.84
							II / 180	1.10
							III / 60	0.82
							III / 120	0.75
							III / 180	0.92
							IV / 60	0.72
							IV / 120	0.83
							IV / 108	1.35

APPENDIX II Detailed statistical results: post-hoc Tukey test

Percentage closer than the critical standoff distance (%)
display type

	1	2	3	4
1	×	-	★★	★★
2	-	×	★★	★★
3	★★	★★	×	-
4	★★	★★	-	×

Standard error of the standoff distance (m)
display type

	1	2	3	4
1	×	-	-	-
2	-	×	-	★
3	-	-	×	-
4	-	★	-	×

Standard error of the standoff distance (m)
airframe speed

	1	2	3
1	×	★★	★★
2	★★	×	-
3	★★	-	×

Standard error of the standoff distance (m)
display × speed

	1	2	3	4	5	6	7	8	9	10	11	12
1	×	★★	★★	-	★★	★★	-	-	-	-	-	-
2	★★	×	-	-	-	-	★★	-	-	★★	★★	-
3	★★	-	×	★★	-	-	★★	★★	★★	★★	★★	★★
4	-	-	★★	×	-	★	-	-	-	-	-	-
5	★★	-	-	-	×	-	★	-	-	★★	★	-
6	★★	-	-	★	-	×	★★	★	★	★★	★★	★★
7	-	★★	★★	-	★	★★	×	-	-	-	-	-
8	-	-	★★	-	-	★	-	×	-	-	-	-
9	-	-	★★	-	-	★	-	-	×	-	-	-
10	-	★★	★★	-	★★	★★	-	-	-	×	-	-
11	-	★★	★★	-	★	★★	-	-	-	-	×	-
12	-	-	★★	-	-	★★	-	-	-	-	-	×

Standard deviation of the lateral speed (m/s)
display type

	1	2	3	4
1	×	-	★★	★★
2	-	×	★	★
3	★★	★	×	-
4	★★	★	-	×

Standard deviation of the lateral speed (m/s)
airframe speed

	1	2	3
1	×	★★	★★
2	★★	×	★★
3	★★	★★	×

RMS camera error (°)
display × speed

	1	2	3	4	5	6	7	8	9	10	11	12
1	×	-	-	-	-	-	-	-	-	-	-	-
2	-	×	-	-	-	-	-	-	-	-	-	-
3	-	-	×	-	-	-	-	-	-	-	-	-
4	-	-	-	×	-	-	-	-	-	-	-	-
5	-	-	-	-	×	-	-	-	-	-	-	-
6	-	-	-	-	-	×	-	-	-	-	-	-
7	-	-	-	-	-	-	×	-	-	-	-	-
8	-	-	-	-	-	-	-	×	-	-	-	-
9	-	-	-	-	-	-	-	-	×	-	-	-
10	-	-	-	-	-	-	-	-	-	×	-	-
11	-	-	-	-	-	-	-	-	-	-	×	-
12	-	-	-	-	-	-	-	-	-	-	-	×

APPENDIX III Instructions in Dutch

Bij de Marine is op dit moment veel belangstelling voor onbemande helikoptertjes (UAV's). Met deze mini heli's kun je ver weg, met behulp van een camera, kijken wat er gebeurt. Alleen, eigenlijk moet je twee dingen tegelijk besturen: de heli en de camera. De heli mag niet te dicht bij het schip komen, anders wordt hij gezien en uit de lucht geschoten. De camera moet zo goed mogelijke video's maken, en altijd gericht zijn op het schip wat je wilt bekijken.
In het experiment moet je dan ook twee dingen doen:
Ten eerste moet je, met behulp van de rechter joystick en de rechter monitor, de camera op het midden van een schip gericht houden. Omdat het schip, en ook de helikopter, bewegingen maken moet je de camera steeds blijven richten.
Ten tweede moet je, met de linker joystick en de linker monitor, de UAV in een cirkel, tegen de klok in, rond het schip sturen.
Je mag <u>NIET dichter dan 2000 meter bij het schip komen</u>. Dat is echt heel erg belangrijk. Je moet echter wel proberen zo dicht mogelijk bij de 2000 meter te blijven, <u>laten we zeggen op 2250 meter gemiddeld</u>. Omdat het schip willekeurige manoeuvres maakt, moet je steeds blijven opletten dat je op de goede afstand zit!
Je gaat eerst oefenen: eerst alleen het schip volgen, dan alleen een cirkel vliegen, dan allebei tegelijk, daarna volgt het experiment.
Tijdens het experiment worden twee dingen gevarieerd: De vliegsnelheid van de helikopter (60, 120, 180 knopen (108, 216, 324 km/h), en de soort informatie die je krijgt over de positie van de helikopter en het schip. De informatie over de helikopter wordt op vier verschillende manieren weergegeven. Welke dat zijn wordt je van tevoren uitgelegd!
Een 'run' van het experiment duurt iets meer dan 3 minuten. Je doet 5 van deze runs achter elkaar, waarna je collega het overneemt en je mag uitrusten.
<u>Als je iets niet snapt of iets anders te vragen hebt kun (moet) je dat altijd laten weten!</u>

Er zijn vier display typen, per dag krijg je er twee:

[1] North-up, digitale afstand
Bij een north-up display is het scherm altijd noord georiënteerd: als jij draait staat de wereld stil, alsof je naar een landkaart kijkt, waar helikopter en schip overheen bewegen. De afstand tot het schip wordt rechts onderaan weergegeven, probeer zoveel mogelijk op ongeveer 2250 m te zitten, en NIET dichterbij dan 2000 m!

[2] Heading up, digitale afstand
Bij een heading-up display is het scherm aan de helikopter geknoopt. Als je draait dan draait de wereld om je heen. Opnieuw wordt de afstand tot het schip rechtsonderaan weergegeven.

[3] Heading up, afstandscirkels
Wederom heading-up: de wereld draait om de helikopter heen. Nu zijn alleen de afstanden grafisch weergegeven: een rode cirkel (2000 m) en een gele cirkel (2500 m), probeer wederom op ongeveer 2250 m te zitten (midden tussen de twee cirkels in) en NIET dichterbij dan 2000 m te komen.

[4] Perspectivisch correct, afstandscirkels
Keek je tot nu toe steeds recht naar beneden, nu kijk je schuin vooruit: de horizon is nog net zichtbaar aan de bovenkant van het scherm. Wederom met de twee cirkels, wederom afstandhouden.

REPORT DOCUMENTATION PAGE

1. DEFENCE REPORT NUMBER (MOD-NL) RP 96-0179	2. RECIPIENT'S ACCESSION NUMBER	3. PERFORMING ORGANIZATION REPORT NUMBER TM-96-A039
4. PROJECT/TASK/WORK UNIT NO. 788.1	5. CONTRACT NUMBER A95/KM/372	6. REPORT DATE 1 October 1996
7. NUMBER OF PAGES 32	8. NUMBER OF REFERENCES 27	9. TYPE OF REPORT AND DATES COVERED Final

10. TITLE AND SUBTITLE

Computer Generated Environment for steering a simulated unmanned aerial vehicle

11. AUTHOR(S)

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12. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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P.O. Box 20702
2500 ES DEN HAAG

14. SUPPLEMENTARY NOTES

15. ABSTRACT (MAXIMUM 200 WORDS, 1044 BYTE)

Two important tasks in operating a Maritime Unmanned Aerial Vehicle (MUAV) are controlling the airframe and its on-board camera. However, the visual information on which the human operator has to perform these tasks is of poor quality, due to the restricted capacity of the down link between MUAV and operator. This leads to performance degradation in search and tracking tasks and loss of situational awareness.
In previous experiments, it was shown that augmentation of the camera image by adding a Computer Generated Environment (CGE) improves performance in controlling the camera and enlarges situational awareness. The present experiment focuses on the possibilities of operating both the airframe and the on-board camera simultaneously, e.g. tracking a target ship while flying a circle around it. The experiment compared performance in four display type conditions: two without augmentation (respectively north up and heading up), and two with augmentation (respectively a 2D CGE and a 3D CGE).
The results show that the CGE is successful in supporting airframe control, without affecting tracking performance. No differences were found between the 2D and 3D CGE, and no differences were found between the north up and heading up displays without CGE. On the basis of these results, it is recommended to investigate the effects of integrating more information into the CGE (i.e. electronic maps), and to explore the possibilities of switching between 2D and 3D. Moreover, more basic knowledge should be acquired concerning the (visual) perception and discrimination of combined airframe, camera, and target motions.

16. DESCRIPTORS	IDENTIFIERS
Data Transmission Human Performance Remotely Piloted Vehicle Target Tracking Unmanned Aerial Vehicle	

17a. SECURITY CLASSIFICATION (OF REPORT)	17b. SECURITY CLASSIFICATION (OF PAGE)	17c. SECURITY CLASSIFICATION (OF ABSTRACT)
18. DISTRIBUTION/AVAILABILITY STATEMENT Unlimited availability		17d. SECURITY CLASSIFICATION (OF TITLES)

VERZENDLIJST

1. Directeur M&P DO

2. Directie Wetenschappelijk Onderzoek en Ontwikkeling Defensie

3. { Hoofd Wetenschappelijk Onderzoek KL
Plv. Hoofd Wetenschappelijk Onderzoek KL

4. Hoofd Wetenschappelijk Onderzoek KLu

5. { Hoofd Wetenschappelijk Onderzoek KM
Plv. Hoofd Wetenschappelijk Onderzoek KM

6, 7 en 8. Bibliotheek KMA, Breda

9, 10 en 11. KLTZ W.F. Visée, MARSTAF/LVRT, Den Haag

Extra exemplaren van dit rapport kunnen worden aangevraagd door tussenkomst van de HWOs of de DWOO.